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Research Article

Achievement of Early Compressive Strength in Concrete Using *Sporosarcina pasteurii* Bacteria as an Admixture

Rakesh Chidara,[1] Rahul Nagulagama,[2] and Smitha Yadav[1]

[1] *National Institute of Construction Management and Research (NICMAR), Pune 411045, India*
[2] *Manipal Institute of Technology, H.No. 1-3-72 Janda galli, Banswada, Nizamabad, Telangana 503187, India*

Correspondence should be addressed to Smitha Yadav; smiyad01@gmail.com

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Often it is observed, attainment of early compressive strength in concrete is a challenge. Researchers have tried various admixtures to achieve the objective. This work addresses the issue of achieving early compressive strength in concrete using a bacterium called *Sporosarcina pasteurii*. The bacterium is characterised with the ability to precipitate calcium carbonate in the presence of any carbonate source and is known for its resistive capacity in extreme temperature and pressure zones. To establish the objective of gain in early strength around 192 concrete cubes were tested at 3, 7, 14, and 28 days and the results compared with controlled concrete. The bacterium was used in combination of chemicals and the dosage proportions were altered to achieve the desired M20 compressive strength at 28 days.

1. Introduction

The compressive strength achieved in concrete is one of the most important and desirable properties of concrete. Many admixtures have been tried by experts to achieve the desired compressive strength. This paper aims at achieving compressive strength in concrete; however, the authors of the paper have tried to use a nutrition medium containing a bacterium named *Sporosarcina pasteurii* as an admixture in concrete. The focus of the work has been to decrease the time taken by the cement to hydrate and achieve maximum strength at early ages. Early strength gain in normal concrete is mainly associated to the water/cement ratio. Mixes with low water cement ratio gain strength more rapidly than those with higher water cement ratio. This is because the cement grains are closer to one another and a continuous system of gel is established more rapidly.

There are actually many different types of accelerators present in the market but the common problems posed by the accelerators are low slump, low initial setting time, and thus reduced workability. These adverse properties of accelerators refrain most of the experts from using the same in concrete. The use of blended cements presently has also been on rise in construction industry; blended cements with a defined amount of cement replaced with flyash are commonly being used. The addition of flyash to cement, however, has little disadvantage; that is, for flyash to hydrolyse and form into a strong component like cement it needs $Ca(OH)_2$. The $Ca(OH)_2$ is a biproduct of cement hydration process; hence for the flyash to form the C-S-H gel it requires calcium hydroxide in adequate quantity and this can occur only if adequate cement hydrolisation takes place. If calcium carbonate is present in cement, the hydrolisation process takes place quickly and inturn provides $Ca(OH)_2$ in requisite quantity for flyash to hydrolyse and give the desired compressive strength.

Sporosarcina pasteurii formerly known as *Bacillus pasteurii* is a bacterium with the ability to precipitate calcium carbonate in the presence of any carbonate source. This microorganism is well known for its resistive properties to resist the harsh conditions of sea water and very high temperatures whichare generally found in shallow waters and in Sahara desert. This bacterium is used in the present work for checking the improvement in the compressive strength of concrete. *Sporosarcina pasteurii* secretes calcium carbonate. This calcium carbonate inturn acts as a positive catalyst for the cement hydration process as discussed by Ramachandran [1], Péra et el. [2], and Kakali et al. [3]. It was found that the *Sporosarcina pasteurii* bacteria attain their maximum activity rate at 16 hours and maintain this till the time the nutrition medium is consumed. Thus the secretion of maximum amount of calcium carbonate takes place only 16 hours after the concrete has been mixed, thus providing enough workable time for concrete. Also it has been seen that this nutritional medium neither allows for the loss in slump nor causes immediate setting of the concrete.

In the present work the bacterial admixture has been added in different compositions and concentrations along with other products like urea, sodium carbonate, calcium chloride, and so forth in differing proportions to study its impact on compressive strength at 3, 7, 14, and 28 days of curing. The compressive strength obtained of bioconcrete that is with *Sporosarcina pasteurii* bacteria is compared with the strength gained by controlled concrete at 3, 7, 14, and 28 days, respectively.

The work also tries to examine the use of sodium carbonate along with the nutrient medium in concrete and simulate the chemical reaction which is the major contribution of the authors to the research wherein earlier only urea had been tried by experts. The below chemical reactions (1) and (2) depict the formation of calcium carbonate that acts like a catalyst for the formation of C-S-H gel which is required for the hydrolization of cement.

Using urea,

$$\begin{gathered} CO(NH_2)_2 + H_2O \Longrightarrow NH_2COOH + NH_3 \\ NH_2COOH + H_2O \Longrightarrow NH_3 + H_2CO_3 \\ H_2CO_3 \Longrightarrow 2H^+ + CO_3{}^{2-} \\ 2NH_3 + 2H_2O \Longrightarrow 2NH_4{}^+ + 2OH^- \\ HCO^{3-} + H^+ + 2OH^- \Longrightarrow CO_3{}^{2-} + 2H_2O \\ Ca^{2+} + CO_3{}^{2-} \Longrightarrow CaCO_3 \end{gathered} \tag{1}$$

(Kashyap and Radhakrishna [4]).

Using sodium carbonate,

$$\begin{gathered} Na_2CO_3 \Longrightarrow 2Na^+ + CO_3{}^{2-} \\ CO_3{}^{2-} + H_2O \Longrightarrow HCO_3{}^- + OH^- \\ Na^+ + OH^- \Longrightarrow NaOH \ \text{(increasing pH)} \\ HCO_3{}^- \Longrightarrow CO_3{}^{2-} + H^+ \\ Ca^{2+} + CO_3{}^{2-} \Longrightarrow CaCO_3 \end{gathered} \tag{2}$$

(experimental work).

2. Literature Review

A novel technique for the remediation of damaged structural formation has been developed by Arunachalam et al. [5] by employing a selective microbial plugging process. In this process the microbial metabolic activities promote precipitation of calcium carbonate in the form of calcite. The microbial sealant, $CaCO_3$, exhibits positive potential to selectively consolidate simulated fractures and surface fissures in granites and sand plugging as reported by Arunachalam et al. [5]. Previous studies with aerobic microorganism (*Bacillus pasteurii* and *Pseudomonas aeruginosa*) showed a significant improvement (about 18%) in compressive strength of cement mortar as shown by Ramakrishnan et al. [6]. The research done by Achal et al. [7] illustrates a 36.15% improvement in the compressive strength of mortar specimens at 28 days prepared with bacterial cells. It is significantly noted that, among the controlled concrete specimens prepared without the inclusion of bacterial cells, the concrete cubes cured in microbial growth medium were stronger than those cured in water, although there was not much significant variation. Research has also showed that the ionic strength of medium containing urea-$CaCl_2$ appeared to enhance the compressive strength of the concrete.

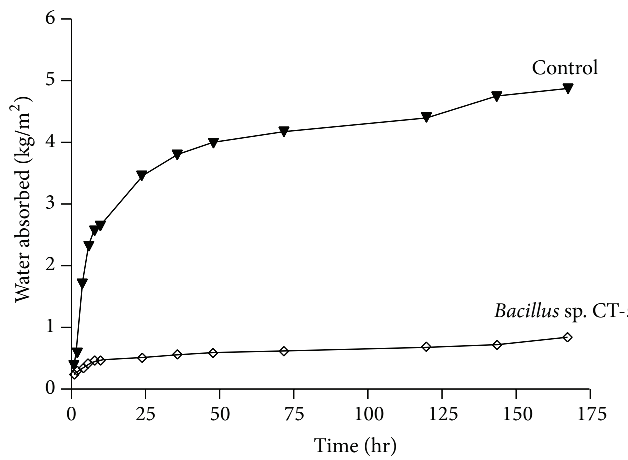

Figure 1: Water absorption experiment on *Bacillus* sp. CT-5 [7].

The improvement in compressive strength by *Bacillus* sp. CT-5 is probably due to deposition of $CaCO_3$ on the microorganism cell surfaces and within the pores of cement-sand matrix, which plug the pores within the mortar as discussed by Supratao [8]. They also found that once the pores in the matrix were plugged, the flow of the nutrients and oxygen to the bacterial cells stopped; eventually the cells either died or turned into endospores and acted as an organic fiber, increasing the compressive strength of the concrete.

The decrease in permeability of mortar specimens treated with bacteria could also be seen from the water absorption experiment. Figure 1 shows a decrease in the water absorption by a CT-5 cube in comparison to control cube. Thus it can be interpreted that the permeability also reduces which is a very desirable property in concrete. This also limits the ingress of harmful substances as reported by Achal et al. [7]. From the experiment, it is clear that the presence of a layer of carbonate crystals on the surface by bacterial isolate has the potential to improve the resistance of cementitious materials towards degradation processes.

Table 1: Composition of chemicals used in bioconcrete.

Sr. number	Concrete mix	Description
1	CC	Normal mix proportions (control concrete)
2	Set 1	Mix proportions + urea 50 mL + nutrient media
3	Set 2	Mix proportions + sodium carbonate 50 mL + nutrient media
4	Set 3	Mix proportions + sodium carbonate 100 mL + nutrient media
5	Set 4	Mix proportions + urea 50 mL + 20 gms of $CaCl_2$/1 ltr + nutrient media
6	Set 5	Mix proportions + urea 10 mL + 20 gms of $CaCl_2$/1 ltr + nutrient media
7	Set 6	Mix proportions + sodium carbonate 50 mL + 20 gms of $CaCl_2$/1 ltr + nutrient media
8	Set 7	Mix proportions + sodium carbonate 15 mL + 20 gms of $CaCl_2$/1 ltr + nutrient media

In 2010-2011 Chahal et al. [9] studied the bacterial isolates on the basis of their calcite precipitation and survival at higher pH. They concluded that the bacterial isolates, which showed increased urease activity, calcite precipitation, and survival at higher pH, could be used in the remediation of cracks in building materials. Thus it was summarised that *Sporosarcina pasteurii* can be used to make concrete with adequate strength and also sustain high temperature and pressures.

3. Materials and Compositions Used

3.1. Mix Compositions. The bacterial admixture has been added in the concrete mix with different chemical compositions like urea, sodium carbonate, calcium chloride, and so forth with varying concentrations as defined in Set 1 to Set 7 to study its impact on compressive strength at 3, 7, 14, and 28 days of curing as shown in Table 1.

3.2. Nutrient Media. The nutrient media were prepared by using a composition of beef extract, yeast, NaCl, and so forth as shown in Table 2. However, the composition of the nutrient medium was changed for different proportions of chemicals added to the concrete mix. Table 2 shows the composition of the nutrient medium with differing chemical compositions to study the effect on the compressive strength of concrete.

3.3. Mother Liquor. The composition of the nutrient media was mixed in mother liquor solution. The process to prepare the mother liquor in the present work consisted of the following steps.

(1) The microbe sample (*Sporosarcina pasteurii*) obtained from the microbial bank is broken and mixed with 10 mL of distilled water.

(2) The distilled water sample is then stored in sterilized conditions.

(3) 50 mL of nutrient medium is prepared and sterilized.

(4) 5 mL of the microbial distilled water is then transferred into the nutrient medium which is then kept on a stirrer at 120 rpm for 24 hours in room temperature.

(5) The microbe starts to grow in the nutrient medium and the nutrient medium is stored in a cold storage room at 4°C for future use.

3.4. Cement. The cement used was UltraTech cement 43 grade ordinary Portland cement (OPC) confirming to IS: 8112-1989 [10] with characteristics as depicted in Table 3.

3.5. Aggregates. The fine aggregates used in the test were natural river sand having a fineness modulus of 2.856. The specific gravity of the same was 2.60. The coarse aggregates for the present work were obtained from local quarry near Manipal having a specific gravity of 2.60 with a fineness modulus of 7.389. Given below in Table 4 is the sieve analysis of coarse and fine aggregates used in the present work. From the sieve analysis it is seen that the sand belonged to zone II as per IS: 383-1970 [11].

3.6. Concrete. Bioconcrete was prepared using the ingredients listed above and adopting the IS: 10262-1982 mix design procedure [12].

4. Test Programme

The test programme consisted of testing concrete cubes of size 150 × 150 × 150 mm at 3, 7, 14, and 28 days using various combinations of nutrient and chemical compositions as depicted in Table 1. The concrete was designed for mild exposure as per the IS mix design method. The water cement ratio adopted for the mix was 0.44 and a slump of 25–50 mm was achieved for all the experiments on slump cone apparatus.

24 cubes of control concrete cubes without the nutrient media were prepared as per IS mix design and 6 cubes each were tested for the compressive strength at 3, 7, 14, and 28 days, respectively.

The bioconcrete cubes were cast using the nutrient medium in differing proportions and also the changing of the chemical constituent, for example, urea or sodium carbonate. With each chemical constituent added to the concrete for studying its impact on compressive strength, 24 numbers of specimen cubes were cast and tested at 3, 7, 14, and 28 days age of curing. The details of the test programme are shown in Table 5. In all around 192 cubes were tested under the mentioned experimental work.

5. Experimental Procedure

The work consisted of testing concrete at 3, 7, 14, and 28 days for achieving 20 MPa compressive strength using admixture

Table 2: Composition of nutrient media.

Sr. number	Desc.	Composition of nutrient media per 1 litre (1) (gm)	(2) (gm)	(3) (gm)	(4) (gm)	(5) (gm)	(6) (mL)	(7) (gm)	(8) (gm)	(9) (gm)	(10) (mL)
1	CC	0	0	0	0	0	0	0	0	0	0 mL of mother liquor
2	Set 1	1	2	5	5	15	1000	4	0	0	20 mL of mother liquor
3	Set 2	1	2	5	5	15	1000	0	4	0	20 mL of mother liquor
4	Set 3	1	2	5	5	15	1000	0	4	0	20 mL of mother liquor
5	Set 4	1	2	5	5	15	1000	4	0	20	20 mL of mother liquor
6	Set 5	1	2	5	5	15	1000	4	0	20	20 mL of mother liquor
7	Set 6	1	2	5	5	15	1000	0	4	20	20 mL of mother liquor
8	Set 7	1	2	5	5	15	1000	0	4	20	20 mL of mother liquor

(1) Beef extract. (2) Yeast extract. (3) Peptone. (4) NaCl. (5) Agar. (6) Distilled water. (7) Urea. (8) Sodium carbonate. (9) Calcium chloride. (10) Bacteria solution.

Table 3: Properties of cement.

Sr. number	Fineness m^2/kg (min)	Setting time in minutes		Soundness		Compressive strength in MPa		
		Initial (min)	Final (max)	Le Chatelier (mm)	Autoclave (%)	3 days	7 days	28 days
1	225	30	600	10	0.8	23.2	33.2	43.4
2	225	30	600	10	0.8	23.1	32.8	43.1
3	225	30	600	10	0.8	22.7	33.1	43.2

Table 4: Sieve analysis of coarse aggregates.

IS sieve size	Wt. retained (gm)	Cumulative Wt. retained (gm)	Cumulative Wt. passing (%)	Wt. retained (gm)	Cumulative Wt. retained (gm)	Cumulative Wt. passing (%)
60 mm	0	0.	100			
40 mm	0	0	100			
20 mm	900	900	55			
10 mm	987	1887	5.65	0	0	0
4.75 mm	104	1991	0.45	25	25	97.5
2.36 mm	9	2000	0	27	52	94.8
1.18 mm	0	2000	0	209	261	73.9
600 μ	0	2000	0	292	553	44.7
300 μ	0	2000	0	412	965	3.5
150 μ	0	2000	0	35	1000	0

Table 5: Test programme.

Sr. number	Set	Composition of concrete per every 1 cube of concrete Nutrient media (lts)	Mix design	Cement (kg)	Fine agg. (kg)	Course agg. (kg)	Water (lts)	Total number of cubes tested
1	CC	0	1 : 1.5 : 3	1.422	2.133	4.267	0.625	24
2	Set 1	0.05	1 : 1.5 : 3	1.422	2.133	4.267	0.575	24
3	Set 2	0.05	1 : 1.5 : 3	1.422	2.133	4.267	0.575	24
4	Set 3	0.1	1 : 1.5 : 3	1.422	2.133	4.267	0.525	24
5	Set 4	0.05	1 : 1.5 : 3	1.422	2.133	4.267	0.575	24
6	Set 5	0.01	1 : 1.5 : 3	1.422	2.133	4.267	0.615	24
7	Set 6	0.05	1 : 1.5 : 3	1.422	2.133	4.267	0.575	24
8	Set 7	0.015	1 : 1.5 : 3	1.422	2.133	4.267	0.61	24

of nutrient medium made up of bacterium *Sporosarcina pasteurii*. Since admixtures require calcium carbonate in adequate quantity for the hydrolisation process, the same was supplemented by using urea which was already tried by researchers. However, supplementation of calcium carbonate required for hydrolisation can also be done by addition of sodium carbonate and calcium chloride. The work thus consisted of adding these chemical components in various compositions. Initially the compressive strength with 50 mL urea was found out and the same repeated with sodium carbonate with compositions 50 mL and 100 mL. Further 20 gm of calcium chloride was also tried along with urea 10 mL and 50 mL urea and the same repeated with 15 mL and 50 mL sodium carbonate. The results of the experimental work are discussed below.

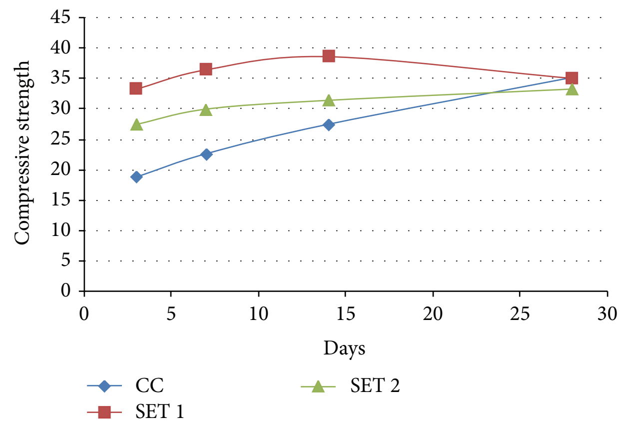

Figure 2: Comparison of control concrete with Set 1 and Set 2.

6. Results and Discussions

(1) Concrete was prepared by using a combination of the bacterial admixture along with 50 mL of urea (Set 1) and also the admixture along with 50 mL of sodium carbonate (Set 2). Urea and sodium carbonate were added to the nutrient media to simulate the reactions as represented in (1) and (2). The compressive strength results in MPa of CC, Set 1 and Set 2 at 3, 7, 14, and 28 days of curing, are shown in Figure 1.

From Figure 2, it is evident that an increase in compressive strength is observed to the extent of 76.6% at the end of 3 days with 50 mL urea, that is, Set 1. However, the compressive strength of Set 1 at 28 days is at par with control concrete (CC). From the above figure it is also seen that this combination showed a gain in strength up to 14 days of curing, beyond which a decrease in strength is noted.

The result with sodium carbonate (Set 2) also represented a similar trend as with urea (Set 1); though in this case the increase in strength was gradual from 3 to 28 days. Set 2 mixes though provided a higher strength at 3, 7, and 14 days; however, strength at 28 days was comparable to controlled concrete. The strength however was marginally (5%) lower than the mix with urea, that is, Set 1. Since this did not contribute to a rise in compressive strength, a slight increase in the percentage of sodium carbonate was tried.

(2) Concrete was prepared by using a combination of the bacterial admixture along with 100 mL of sodium carbonate. Sodium carbonate was added to the nutrient media in higher amount to provide the necessary calcium hydroxide required for the hydrolisation process. The test results of CC, Set 3 at 3, 7, 14, and 28 days of curing in MPa, are shown in Figure 3.

From the observation of results attained by adding 100 mL sodium carbonate to the nutrient medium to prepare concrete, that is, Set 3, it is observed that there is increase in compressive strength up to 14.4% at 3 days and around 43% at 7 days. However, this rise beyond 7 days is found to be moreover constant till the 28 days of curing. It is noticed that these compositions of Set 3 showed a slight decrease in compressive strength around 2.6% in comparison to that of the control concrete at 28 days of curing. Since this composition also did not give any substantial change in compressive strength, the formulation of the nutrient media

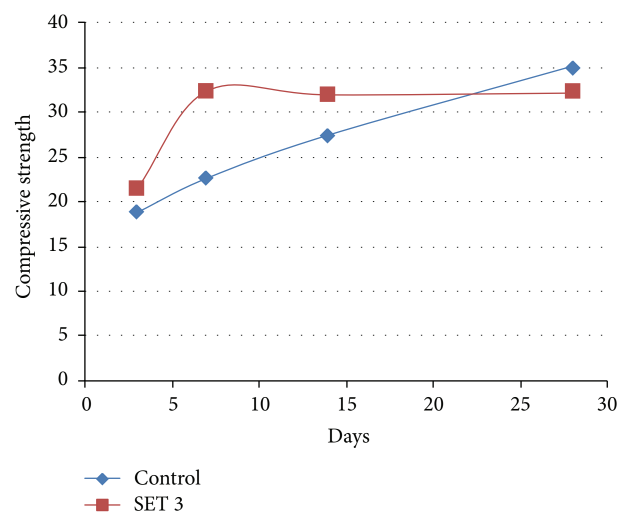

Figure 3: Comparison of control concrete with Set 3.

was further altered by addition of calcium chloride to the nutrient media along with urea or sodium carbonate.

(3) In the next set of work $CaCl_2$ was added to the nutrient media as was also carried out by researchers Varenyam Achal et al. [7]. The amount of nutrient media added was 50 mL/cube and this was tried with both the nutrient media bases, that is, urea and sodium carbonate and the results obtained are shown in Figure 4.

It is observed from Figure 4 that when nutrient media based on urea (Set 4) were used, there was an increase in compressive strength up to 14 days; however, the compressive strength observed at 28 days was less than that of the 28 days strength of controlled concrete.

The above figure also shows that when nutrient media based on sodium carbonate (Set 6) were used, then there was an increase in strength up to 33.74% at 3 days, 25.9% at 7 days, and 18.53% at 14 days when compared to control; however, the strength obtained at the end of 28 days was similar to that of control.

(4) As the results obtained by adding the nutrient media consisting of $CaCl_2$ gave some positive results, the same

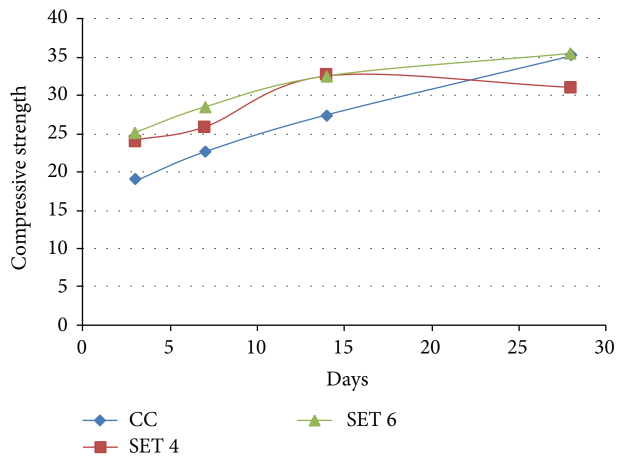

FIGURE 4: Comparison of control concrete with Set 4 and Set 6.

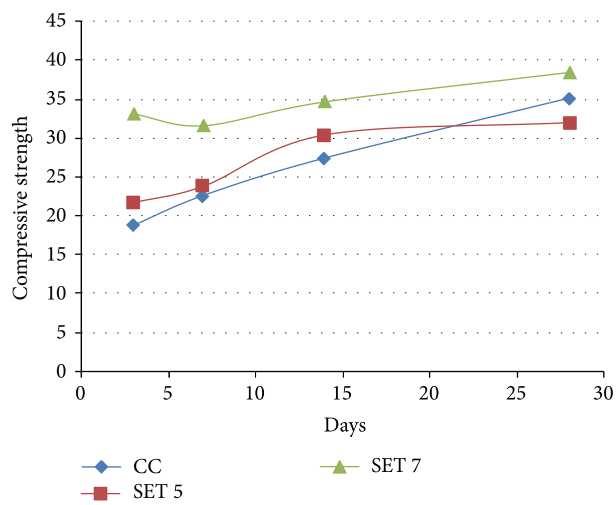

FIGURE 5: Comparison of control concrete with Set 5 and Set 7.

amount of $CaCl_2$ was added again to the concrete; however, the amount of urea was decreased to 10 mL/cube (Set 5) and sodium carbonate taken as 15 mL/cube (Set 7). The trend of compressive strengths gained by the concrete by the change is represented in Figure 5. It is observed from the above figure that there was slight increase in the compressive strength with Set 5 but the gain at 28 days was comparable to that of controlled concrete. Figure 5 also shows that there was increase in strength when Set 7 combination was used in concrete. There was an increase in strength up to 75.8% at 3 days, 39.6% at 7 days, 26.24% at 14 days, and 9.35% at the end of the 28 days when compared to that of control concrete. This gain of strength has been attributed to the *Sporosarcina pasteurii* bacteria as this secretes calcium ions which in turn react with the carbonate ions and form calcium carbonate as shown in (2). This calcium carbonate does not directly react with the cement particles (C_3S, C_2S, C_3A, and C_4AF) but instead it acts like a catalyst for the cement hydration reaction as shown in (3) thereby fastening the process of hydration and increasing the strength of concrete thus produced

$$C_3S, C_2S, C_3A, C_4AF + H_2O \longrightarrow \text{C-S-H gel} + Ca(OH)_2 \quad (3)$$

This calcium carbonate if added manually actually moreover acts like an accelerator which actually decreases the setting time of concrete and thus may not be acceptable. In the present work the calcium carbonate is produced in adequate quantity after the bacteria reach their maximum activity that is 16 hrs allowing enough working time. Thus it can be summarised that *Sporosarcina pasteurii* bacteria when added to concrete in proper proportions results in early strength gain of concrete without affecting the initial setting time.

7. Conclusions

(1) It can be concluded that the use of *Sporosarcina pasteurii* bacteria leads to early strength gain and also leads to overall increase in the compressive strength of concrete.

(2) The results obtained by both sodium carbonate and urea were found to be almost similar and thus sodium carbonate can also be used as a substitute to enhance strength in concrete.

(3) The highest gain in compressive strength was obtained when admixture which constitutes of sodium carbonate and calcium chloride was added to the concrete mix.

(4) The addition of the admixture consisting of *Sporosarcina pasteurii* bacteria affected neither the slump nor the initial setting time of concrete.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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